Growing Energy
Land for Biomass Farms

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ABSTRACT

Biomass crops grown for energy conversion require high-quality land to maximize energy gain and minimize environmental hazards. The shortage of such land may hinder development of energy farms. Most of the 760 million acres of classes I-IV rural land of sufficient quality to support biomass production would need considerable conservation measures to overcome inherent development problems. Furthermore, alternative sources of food and fiber production would need to be found if the land were diverted to energy farms.

KEYWORDS: Biomass, Energy farms, Land, Land quality, Energy, Costs of production.

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HIGHLIGHTS

Mushrooming energy consumption, depletion of fossil energy sources, and concern about the safety of nuclear energy are forcing the consideration of alternative energy sources. One of these alternatives is biomass grown on energy farms.

Reliance upon biomass crops is seriously hindered by two factors. First, biomass farming requires large amounts of energy as do most of the processes for converting the energy in biomass to other forms of fuels and chemical feedstocks. Second, high-quality land is needed for biomass farming. The quality of land in production is directly related to the energy output-input ratios and inversely related to the dangers of environmental degradation from biomass production.

Perhaps over 90 percent of the 470 million acres of U.S. cropland is of sufficiently high quality to support biomass production, although about half this land needs considerable conservation measures to prevent soil and environmental degradation. In the short run, however, rising food demand spurred by growing world population and rising incomes may edge out biomass production in the competition for high-quality land.

About 220 million acres of pasture and rangeland fall in the Soil Conservation Service (SCS) top four land capability classes and thus have potential for sustaining biomass crops. In addition, approximately 160 million acres of forest land might be suitable for growing biomass for energy. SCS estimated that approximately 100 million acres of classes I-IV pasture, range, and forest land have high or medium potential for cropland development given the favorable 1974 price/cost relationships. Such land may be suitable for production of a biomass crop given an adequate price/cost relationship. However, the diversion of even good quality pasture, range, and forest lands to biomass production will usually require some investment. Approximately 60 percent of the 74 million acres of land with high potential for cropland development would require onfarm, multifarm, and/or project development to crop the land. Over 80 percent of the 27 million acres of medium potential land would require such development.

Withdrawal of cropland, pasture, range, and forest lands for biomass farms or any other use might conflict with the growing demand for food, feed, and fiber products.

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INTRODUCTION

The world faces an energy dilemma. We recognize the limits of our preferred energy sources (oil and gas) and are contemplating the viability of possible alternative major sources (coal, geothermal, solar, and nuclear). However, we do not have definitive information on the benefits, costs, and risks involved in utilizing these alternate sources.

The use of biomass, organic materials generated originally by photosynthesis, to produce chemical energy is one of the ways that has been proposed to utilize solar energy. The U.S. Department of Energy (DOE) funded over $23 million in fiscal year 1978 in research contracts on the potential use of biomass for energy (34) 1/.

The central issue concerning the practicality of energy from biomass revolves around the economics of production. The feasibility of using biomass as an energy source depends upon the cost of producing the biomass feedstock and the cost of converting the chemical energy in biomass to other usable forms of energy. Biomass can be obtained as a byproduct of other activities or it can be grown on energy farms. The feasibility of using residues depends upon its value for alternative uses. The practicality of energy farms depends upon the availability of inputs--land, water, labor, capital--and the value of these inputs for other uses. The economic viability of using the energy in biomass depends upon the location of biomass, the nature of the biomass material, the type and efficiency of the conversion processes, and the location of the markets.

This report examines one of those factors which affects the feasibility of significant energy production from biomass--the land requirements and condition of supply for primary biomass production (energy farms) for energy generation. The availability of land depends upon current uses of and future demands for land resources which are potentially suitable for biomass production, returns from the nonbiomass uses, and possible returns from biomass production.

1/ The underscored numbers in parentheses refer to references listed at the end of this report.

As a preliminary to the analysis, current research on the cost and the energy and land requirements for biomass production is reviewed. Then, U.S. Department of Agriculture (USDA) data on the costs of and the energy used for crop production are used to determine the ability of energy farms to compete for land resources. Estimates are made on the amount of land potentially available for primary biomass production in light of the competing demands for land and the quality limitations of the land base. Throughout the report, discussion will concern land use in the 48 contiguous United States.

The following synopsis will highlight general issues underlying the consideration of biomass as a major energy source. Through the process of photosynthesis, sunlight is absorbed by the chlorophyll in the leaves and stems of green plants. Using the energy in sunlight, the chlorophyll reforms water and carbon dioxide into carbon compounds. Chemical energy is stored in the carbon compounds in plant materials. The energy in biomass can be used directly by burning biomass for heat or electricity generation. Through various chemical conversion processes, fuels and chemical feedstocks can be obtained from biomass. Methanol can be synthesized from wood. Grains can be fermented to obtain ethanol.

A number of positive and negative reasons have been advanced for tapping the solar energy captured by photosynthesis in biomass. On the positive side, the production of fuel and chemicals from biomass involves less risk than does nuclear energy and does not generate the dangerous wastes. Unlike fossil fuels biomass is renewable. The lower sulfur and ash content in biomass would decrease the environmental pollution from burning. The sulfur content of plant matter is generally below 0.1 percent; the average sulfur content of coal is about 2.5 percent (23, p. 49).

Photosynthesis stores energy in organic matter. Other methods utilizing solar energy require separate energy storage facilities. Many biomass sources, such as crop residues and urban wastes, currently are wastes which must be disposed. Utilizing them as sources for fuel and chemical feedstocks can offset some of the costs involved in disposing of them.

Although the exact extent of fossil fuel reserves and the rate of future consumption may be disputed, the decreasing volume of sources and increasing difficulty in tapping the remaining supplies will certainly increase prices of these energy sources. Projected costs of energy from nonbiomass sources are presented in table 1. The increased costs, increased scarcities, and variability in supplies of fossil fuels should enhance the attractiveness of other sources of energy.

On the negative side, photosynthesis generally converts less than 1 percent of incoming solar energy to chemical energy. Even under very favorable conditions efficiency does not exceed 4 percent (23). Biomass production tends to be spatially diffuse, perishable, and bulky, and therefore costly to collect and transport to processing facilities. The energy value per ton is much lower than the energy value per ton of fossil fuels or nuclear sources. Crude oil contains 38 million Btu per ton. Dried plant matter contains 13 million Btu per ton. The energy content falls to about 4 million Btu per ton if biomass is not dried, about the same as oil shale and tar sands.

Table 1--Oil and coal price estimates, 1985

Commodity	Price per million Btu
	Dollars 1/
Domestic oil price tiers 2/	
Third tier	3.78
Lower tier	1.36
Upper tier	3.05
Stripper	3.75
North Slope	2.65
Average	3/ 2.90
Coal 4/	
Low sulfur bituminous	1.63
High sulfur bituminous	1.23

1/ 1978 dollars.

2/ Energy Policy and Conservation Act regulated wellhead prices. Price tiers referring to classes of crude oil production established for pricing purposes are defined: (1) third--discoveries after April 20, 1977; (2) lower--quantities under production in pre-embargo base period; (3) upper--oil produced in excess of lower tier base, but not a new discovery; (4) stripper--wells producing less than 10 barrels per day; (5) North Slope--oil produced on North Slope of Alaska. The average price is weighted by the projected level of production from the various domestic sources.

3/ Equivalent with $17 per barrel of crude oil. There are 5.8 million Btu in a barrel of crude oil.

4/ Delivered coal prices to electric utility sector under medium demand, medium supply situation.

Source: (36)

CURRENT RESEARCH REVIEW

Energy farms would be operated to produce biomass to be used for fuel and chemical feedstock production. These energy farms could operate upon either a base of land or water. Three main types of biomass production are considered: (1) silviculture, (2) crop production, and (3) aquaculture.

The following analysis is a summary of both current research on the costs of producing biomass on energy farms (standardized to Btu units) and also of estimates of the acreage needed to produce a given amount of energy. More information on the particulars of these research projects is presented after the summary.

Estimates of Cost of Biomass Energy

Estimates in recent literature of the cost of energy in unprocessed biomass produced by silviculture, grass, and sugar crop production range from less than $1 to more than $3 per million Btu (table 2). Some of the estimates are for specific crops grown in specific localities. Other research is of a more hypothetical nature specifying neither a particular crop nor a particular location. The estimates vary not only because of these differences but also because the assumptions concerning productivity and the costs of inputs and the methods of calculating costs differed vastly between research projects (see footnotes to table 2 and detailed summaries). None of the estimates includes the costs of conversion from chemical energy in biomass to a more usable source energy, such as heat, methane gas, electricity, or ethanol. Costs for these conversions, which will include expenditures for additional energy inputs, will most likely be higher for biomass than for fossil fuel sources. Some investigators have considered neither return on investment nor transportation expenses in figuring cost of energy produced by growing biomass. Table 3 summarizes the results of those investigations in which the return on the investment was included in the cost of production. Estimates from current literature on the amount of land needed to produce a specific amount of energy have been standardized for comparison in table 4. Diversity

Table 2--Estimated costs of energy in biomass crops grown on energy farms

Crop	Cost per million Btu
	Dollars
Slash pine (Louisiana) 1/	1.86
Silviculture 2/	1.21 - 2.47
Corn 3/	1.13
Corn (Iowa) 1/	2.03
Deciduous plant material 4/	1.22
Napier grass (Puerto Rico) 1/	1.27
Sugarcane 5/	2.84 - 3.29
Sugarcane 6/	.65

1/ Estimate does not include cost of transporting or drying the biomass (24).

2/ Estimate based on high rates of productivity and does not include cost of drying (15).

3/ 1972 costs of silage corn production do not include drying or transportation and assume a high solar conversion rate of 0.7 percent (16).

4/ Particular crops are not specified; estimate does not include drying material (27).

5/ 1976 actual production costs do not include drying or return on investment (22).

6/ Estimate for California at 30 dry tons/acre does not include drying costs or return on investment (1).

Table 3--Estimated returns for biomass crops

Crop	Price per million Btu	Annual returns on investment per acre 1/	
	Dollars	Dollars	Percent
Slash pine (Louisiana) 2/	1.86	40	21
Silviculture (Louisiana) 3/	1.21	24	10
Corn (Iowa) 2/	2.03	40	18
Deciduous plant material 4/	1.22	14	11
Napier grass (Puerto Rico) 2/	1.27	40	11

1/ Exclusive of land costs.
2/ (24).
3/ Discounted cash flow rate of return (15).
4/ Allowable gross returns (27).

Table 4--Estimated acreages of land needed to produce 8 quadrillion Btu of energy

Crop	Acreage
	Millions
Silviculture 1/	83
Farm or forest crop 2/	20
Farm or forest crop 3/	40
Deciduous plant materials 4/	78

1/ (15).
2/ Estimate of low cost, high yield situation; includes conversion to methane gas (37).
3/ Estimate of high cost, low yield situation; includes conversion of methane gas (37).
4/ (27).

in the methods of calculating the cost of producing biomass for energy complicates interstudy comparisons. Standards need to be formulated to facilitate such comparisons.

Energy Cost and Land Requirements Underestimated

Costs of energy in biomass and land needed to grow given quantities of biomass are underestimated in varying degrees by most of the current research. The yield levels are often unrealistically high; the costs for quality land are unrealistically low. A serious defect is that in current research generally the estimate on the costs of and the land needed for biomass production per energy unit contained is calculated on the total energy content of the harvested biomass. In fact, the final energy output resulting from use of biomass is at present considerably less than the amount of energy contained in the biomass. Conversion of the chemical energy in biomass to heat or different fuels is less efficient than the conversion of current fossil energy sources to heat or other fuels. Burning is presently the most efficient conversion process for biomass. The efficiency of generating heat by burning varies depending upon the moisture content of material which is burned. For example, one study estimated that burning wood with a 30-percent moisture content would yield 75 percent of the original energy content. But burning wood with 60-percent moisture content would yield 60 percent of the energy in the wood (8, p. 28). If a crop such as alfalfa was sun dried before it was burned for heat energy, the efficiency of the process might be fairly high. But areas of the country where air drying of biomass is most feasible tend to be moisture-deficit areas where energy intensive irrigation is necessary to maintain high production yields. Processes for converting biomass to other fuels such as methane or ethanol are being developed and refined. Conversion efficiencies yielding up to 100 percent of the original energy content of the biomass are envisioned (21). However, they have not been obtained on an operational basis. The result of the inefficiencies of the biomass conversion processes is that the final cost of energy from biomass will be at least twice or, more likely, several times higher than these estimates have suggested.

Summaries of Investigations on Biomass Production

The following summaries highlight the methods of calculating costs of biomass production and of estimating the quantity of land needed and available for biomass production for the research summarized in tables 2, 3, and 4.

Silviculture

Silviculture energy plantations have the production of wood for energy feedstock as a primary product. Mitre Corporation, under contract to DOE, conceptualized the operation of 10 such plantations optimally sized at 37,000 acres each throughout the United States (15). Each of these plantations would produce 250,000 dry tons of biomass per year. With this production rate, 235 such plantations, or approximately 8.7 million acres, would produce 1.25 percent of the U.S. annual energy consumption. To provide 10 percent--or 8 quadrillion Btu--of the 1980 U.S. energy consumption would require 70 million acres. However, if only the actual average acreage requirements of the preferred sites (44,000 acres) are considered, then 83 million acres would be required to supply 8 quadrillion Btu of the annual U.S. energy use. As conceptualized by Mitre, the preferred sites do not involve use of prime agricultural land, public land, or swampland.

Mitre concluded that, given the yields ranging from 5 to 13 dry tons per acre on planted acreage and including a 10-percent rate of return, biomass could be sold for between $1.21 and $2.47 per million Btu. Based upon Mitre analysis, average annual returns per acre (10 percent before taxes) varied from about $25 at the Louisiana site to $34 at the Illinois site under current conditions. Mitre concluded that production costs depend mainly upon the rate of productivity. The same is true for the amount of energy used to produce the biomass. At higher yielding sites, the costs of production and the energy inputs are less per unit of biomass produced. At the same time, Mitre concluded that use of prime agricultural land is discouraged by the increase in production costs due to high land costs.

Mitre identified the amount of land potentially available for biomass production in the United States (25). Potentially suitable land (1) had to have at least 25 inches of precipitation annually and (2) had to be included in Soil Conservation Service (SCS) capability classes I-IV or U.S. Forest Service (USFS) commercial forest site classes I-IV. The second criterion eliminated nonarable and steeply sloped (over 30 percent) land. Combining this information with land use information, Mitre generated six scenarios of potentially available land for 9 of the 10 farm production regions. Mitre concluded that the most likely scenario entailed using SCS classes I-IV noncropland for silviculture energy plantations.

Field Crops

Kemp and Szego estimated that at a solar conversion rate of 0.7 percent (which is high but not unrealistic) and with cost estimates based on growing, harvesting, and chopping corn for silage, biomass from corn to be used for electricity generation would cost $1.13 per million Btu in 1972 (16). The assumed production of 11.1 dry tons per acre per year is overly optimistic. At the time of the Kemp-Szego study, the cost of other fuels for electrical generation ranged between about $0.35 to $0.55 per million Btu.

The energy plantation concept developed at Inter-Technology Corporation emphasized the importance of finding the optimum energy crop and production practices for each site (27). Inter-Technology considered deciduous trees and warm summer grasses the most promising vegetative sources of energy. Minimum plantation size was estimated to be 28,500 acres if the maximum annual production per acre is 9 oven dry tons and if harvesting and transportation equipment are fully utilized.

They estimated that four such deciduous-producing plants operating in close proximity could produce energy at the cost of $1.22 per million Btu. The value of land rented for the energy plantation was estimated to be $239 per acre. The type of land considered suitable was to be in low population density areas, to receive more than 2 inches of rain per month during the growing season, to have a slope of less than 25 percent, and not be in current use for cropland, commercial forest, pasture, range, or recreation. Natural soil fertility was not considered as important as proper drainage. Inter-Technology estimated that there are 175 million acres of such land available and privately owned.

An advantage of field crops with high sugar content as an energy source is that much of the biomass produced is in the form of directly fermentable simple sugars. Lipinsky and McClure, at Battelle's Columbus laboratories, concluded that of the sugar crops, sugarcane has the greatest near-term potential as an energy source if yield versus geographical area tradeoffs are considered (22). Their research emphasized the association between land quality and biomass yields. Despite expected increases in yields per acre, additional land must be brought into production if sugar is to become an important source of fuel and chemicals. Sugarcane's very high temperature and water requirements for maximum production severely limit the amount of U.S. land capable of meeting these requirements. Lipinsky and McClure's estimate of costs of sugarcane biomass production included cost of land, inputs, harvesting, and transportation to processing facility; costs were based on 1976 USDA information on actual costs of sugarcane production. Their estimate did not include return on investment, losses in drying the material, or cost of conversion of the biomass to fuel or chemical feedstock.

The cost of energy from sugarcane biomass calculated by Lipinsky and McClure is much higher than most other estimates; Battelle's figures, however, are based upon firm data on current yields and production practices and include transportation as well as most other costs. Most of the other studies' cost estimates for production of biomass for energy are based upon less firm cost estimates, include assumptions about increased yields and improved management practices, and/or do not include all costs associated with production and transportation to processing facilities.

In a 1974 report to the National Science Foundation, Alich and Inman concluded that "...the primary potential region for the location of biomass plantations is the Southwestern United States, principally the States of Arizona and California" (1, p. 14). They acknowledged that biomass production on a large scale in this region is not feasible without the development of a large supplemental supply of water, and they suggested that the most effective source of water would be interbasin water transfer from areas of water surplus. Their estimate of the likely cost of biomass for energy use was less than a dollar per million Btu. However, they did not include in their analysis the costs of development of a large supplemental supply of water, nor did they evaluate the political realities of interbasin water transfers.

Conclusions about the viability of biomass as an energy source made in a 1975 study by Roller and others were not so optimistic as the other studies cited (24).

> The conclusion is drawn that climate, land availability, economics of agricultural production and marketing, food demand, fertilizer shortage and water availability all combine to cast great doubt on the feasibility of producing grown organic matter for fuel in competition with food, feed or fiber, on U.S. acreages. The feasibility of collecting residues may be nearer, but the competition for residues for return to soil or celluloic production is formidable.

Yields and costs of production were examined for nine species of plants which seem best suited for biomass production in various areas of the United States. The yields were actual yields under uncontrolled water and temperature regimes but with adequate nutrients and no disease problems. Costs of production for the six crops which showed the greatest biomass production potential (considering yields and areas suitable for cultivation) ranged from $1.27 per million Btu for napier grass to $2.87 for alfalfa. Costs included land, return on investment, machinery, labor, fuel, fertilizer, and seeds. Costs of transportation to processing facility and costs of conversion to another form of energy were not included.

This study concluded that biomass production would not be a competitive use of present agricultural and forest land, given the free enterprise system and the comparative value of food and fiber crops. A further conclusion was that use of marginal land for biomass production was not feasible because decreased yields and increased production costs will raise the costs of production per unit even higher. Environmental complications because of slope or loss of organic matter render much marginal land unsuitable for removal of all biomass.

The study used the 1958 SCS Conservation Needs Inventory's land use and land quality data with the additional requirement that the land receive an average of 20 inches of rainfall per year to calculate the amount of land possibly available for biomass production. Estimates were that there were 270 million acres of pasture and forest land physically suitable for energy farms.

Aquaculture

Another source of biomass for energy production is aquaculture. Biomass from this source seems especially promising in terms of predictions of high yields per acre and of waste products being used as a culture medium. However, estimates concerning the viability of this organic energy source are based on the least practical experience. The component of aquaculture which would be in competition with present land uses is fresh water farming. Greeley advocated algae production as a direct source of energy or as cattle feed, thereby freeing pasture and rangeland for biomass for energy production (12). He estimated that with yields of 30 dry tons per acre per year, 8 million acres could produce enough feed to equal the 1974 forage feed supply. He estimated that waste water ponds, which could be used for algae production, may cover 20 million acres by 1985 if provisions of the Clean Water Amendments of 1972 are carried out.

ECONOMICS AND USE OF ENERGY IN BIOMASS PRODUCTION

Growing biomass for energy should be subject to biological considerations and production practices and costs similar to those presently applicable to silviculture and crop production. Many of the cost estimates on biomass farming in the preceding section were based upon optimistic assumptions concerning yields, economies of scale, and management expertise. It is reasonable to assume that advances both in the efficiency of photosynthesis and in production practices will be achieved and adapted as readily by the agriculture and forestry sectors. Although the need for alternate energy sources is becoming more acute, the long-term need for U.S. food and feed will also become more critical and the demand for wood products will continue to grow. Therefore, agriculture, forestry, and biomass production are likely to have to compete for the same inputs while remaining subject to similar biological, technological, legal, and managerial constraints.

Because biomass production will be similar to crop and forest production, the costs of biomass farming, the returns necessary to compete with agriculture or silviculture, and the cost of energy and the net energy gain from biomass may be put into clearer perspective by considering the production budgets, yields, and energy output/input ratios for particular crops. Three of the four examples in table 5—corn, alfalfa, and sycamore—are crops which involve growing the most above surface vegetative matter, the same end sought in biomass production.

The raw material price for biomass at the farm gate as an energy source ranged upward from $3.15 per million Btu except for sycamores (table 5). However, the sycamore budget is based upon very limited experience of growing trees for pulp use.

> In the absence of a short-rotation sycamore stumpage market, crop values are necessarily speculative and are here based on values of analogous wood products. The hardwood chip market was the basis for deriving sycamore stumpage prices. (6)

The cost of energy from these and similar biomass crops would be higher today because of increased costs of inputs. In comparison, the cost of energy contained in crude oil in December 1977 ranged from an average of about $1.50 per million Btu for domestic oil to $2.50 for imported oil. 2/ The differences in price of energy from crude oil versus biomass is even greater when the final price of energy paid by the consumer is considered. The conversion efficiency rates for energy products from biomass are much lower than the efficiency rates for crude oil. Biomass is generally bulky, perishable, and seasonal, necessitating specialized storage facilities and utilization schedules. The spread between price of energy from biomass and other major sources would be correspondingly great.

Under present conditions, if biomass is competitive with agriculture for inputs including land, it cannot be competitive with other sources of energy. If biomass is competitive with other energy sources, biomass farms cannot pay for the inputs necessary for its production, including bidding away quality land from crop production. Whereas the preceding comparisons of prices of energy from biomass against current energy sources are not precise, they do indicate that circumstances must change greatly before biomass is competitive with agriculture for inputs of production. A surplus agricultural situation caused by one or more of the following could possibly free quality land for biomass production:

- decreased domestic and world demand
- limitation of food, feed, and fiber exports
- higher per acre productivity

It is unlikely that (1) demand for U.S. agricultural products will experience slower future growth, much less decline, and (2) the United States will be able either politically or economically to drastically limit food exports.

2/ Based upon DOE data of $8.70 per barrel average domestic price at the wellhead and $14.77 average price of imported oil at U.S. refineries as of December 1977 (35).

Table 5--Annual yields and returns per acre for producing selected crops and prices and output/input ratios of energy produced

Crop	Yield	Gross receipts	Land charge	Management	Return to overhead and risk	Price per million Btu of energy in the unprocessed biomass 1/	Energy output input ratio 2/
	Dry tons	---	---	---	Dollars	---	Btu
Corn for silage: 3/							
Michigan	3.8	183	45	13	-23	3.76	3.5
Missouri	3.0	152	39	11	-13	3.89	3.3
Nebraska-irrigated	4.6	228	55	16	- 5	3.80	5.1
Indiana	4.6	264	45	22	45	4.36	4.9
South Dakota	1.7	89	18	6	-11	3.97	4.1
Sugarcane: 3/							
Florida	12.3	584	251	29	-120	3.66	8.8
Louisiana	8.9	412	90	21	22	3.54	5.9
Texas	13.2	560	123	28	39	3.25	4/
Alfalfa for hay: 3/							
California-irrigated 5/	6.3	386	30	27	81	4.71	9.0
Iowa 6/	3.3	171	45	12	51	3.99	7.8
Michigan 6/	2.8	117	25	8	17	3.15	8.4
Oklahoma 5/	3.2	183	23	13	65	4.39	7.3
South Dakota 6/	2.1	104	14	7	48	3.80	10.7
Sycamore 7/	4.7	93		28		1.32	8/ -

1/ Calculated by dividing the gross receipts per acre by the energy content in an acre of harvested matter. For sugarcane, the weight of available cane was used to calculate the gross receipts; the total harvested matter, millable cane plus tops and leaves, was used to calculate the energy content per acre. 2/ Calculated by dividing the energy content of dry harvested material per acre by energy input per acre. Primary data source for average yields and inputs was (31). Input data estimated energy for fuel, fertilizer, and pesticides, but did not include energy for labor or for manufacture of equipment. 3/ Adapted from Firm Enterprise Data Systems (FEDS) budgets prepared by the Commodity Economics Division, ESCS, in cooperation with Oklahoma State University. Data are for 1975 except for Michigan (1976). 4/ Unavailable. Energy used for irrigation of sugarcane not identifiable from this source. 5/ Costs of establishment prorated over 5 years. 6/ Costs of establishment prorated over 4 years. 7/ Adapted from optimal budget for sycamore production for reconstituted wood products published in (6). 8/ Unavailable.

Agricultural productivity may have difficulty maintaining, much less increasing, the growth rate of the past three decades because of constraints imposed by increased input costs and growing environmental concerns.

More probable trends positively affecting the viability of biomass as a raw material for U.S. energy production are (1) increasing scarcities of preferred energy sources resulting in higher energy prices and (2) growing concern about the environmental dangers posed by alternative energy sources. However, biomass production itself will be negatively impacted by these same trends. Production costs will increase as growers pay higher prices for high energy inputs—fuel, fertilizers, and equipment. The tradeoff of decreasing these inputs will result in lower yields and not likely bring down per unit costs of energy. Biomass production poses formidable environmental dangers by subjecting more land and water resources to fertilizers, pesticides, and erosive situations. Actions to counteract these dangers will further inflate the price of energy from biomass. Increasing the efficiency of conversion of energy in biomass to common fuels and chemicals is a promising route to narrow the price differences between energy from biomass and energy from other sources. Increasing the energy output/input ratio for biomass production by minimizing energy inputs while maintaining yields is also a crucial research area.

BIOMASS COMPETITION FOR LAND

If the price of energy from nonbiomass sources increases so that energy produced from biomass is competitive, biomass farming may enter the competition for land resources. However, increasing prices of energy will also further increase the costs of biomass production and the costs of energy in biomass. Perhaps a more likely cause of competition for land by biomass production will be Government subsidies resulting from political and environmental concerns. However, biomass production could also have adverse environmental impacts. To minimize loss of soil, deterioration of soil structure, and water pollution from nonpoint sources will mean that biomass production will have to utilize high quality land and careful management practices.

Land Requirements for Biomass Production

The acreage in biomass production needed to meet a given level of energy output depends upon the particular crops, the level of inputs and resulting yields, and the efficiency of the process of converting the energy in biomass to other forms of energy. The energy content per pound and the yield vary by crop. Yield also varies by level of inputs such as land quality, amount of fertilizer and pesticides, and supplemental water. In the near future, direct burning for heat is the sole operational process that will realize 50 percent of the energy contained in the biomass.

To provide a basis for analyzing U.S. land resources in view of land required for biomass farms for energy, biomass acreage requirements to supply 8 quadrillion Btu have been estimated (table 6). This is slightly more than 10 percent of the 1977 total energy use for the United States. The current National Energy Plan goal is to reduce the annual growth of total U.S. energy demand to below 2 percent (7). (Between 1968 and 1976 the annual rate of

Table 6—Estimates of total acreages to supply 10 percent of U.S. energy needs

Crop and State	Acres to supply 8 quadrillion Btu 1/
	Millions
Corn:	
Michigan	324
Missouri	410
Nebraska-irrigated	268
Indiana	268
South Dakota	724
Sugarcane:	
Florida	100
Louisiana	138
Texas	93
Alfalfa:	
California	195
Iowa	373
Michigan	440
Oklahoma	384
South Dakota	586
Sycamore, Georgia	226

1/ Based upon yield assumptions presented in table 5.

growth was 2.3 percent.) With an annual growth rate of 2 percent, 8 quadrillion Btu would be 8 percent of the 1980 total U.S. energy use.

The biomass acreage estimates in table 6 are based upon the same crop and yield assumptions used in constructing table 5 and assume a 50-percent average conversion rate of the energy in biomass to usable energy in heat and fuels. Furthermore, the estimates are for planted acreage and do not include land for rotation, farmsteads, and roads. Substantial additional acreages may be needed so that the biomass crops can be rotated with a conservation crop to help maintain nutrient and humus content of soils. An alternate way to retard erosion and nutrient and humus loss is to harvest only part of the vegetative matter. Such a strategy would likewise entail higher acreage requirements for biomass production.

These rough estimates suggest the magnitude of the land input needed for biomass farms. Approximately 300 million acres of land planted to corn could perhaps meet 10 percent of current U.S. energy needs--if the assumption concerning conversion efficiency was also met (table 6). Currently there are less than 100 million acres in corn production for food and feed.

Likewise, approximately 100 million acres in sugarcane might be able to supply 10 percent of our current energy needs. Sugarcane production has very high moisture and temperature requirements. There are currently less than a million acres of sugarcane in the United States. Alternatively, it would take somewhere between 200 and 500 million acres of alfalfa to meet 10 percent of our present energy needs. There are currently about 25 million acres in alfalfa. Total cropland used for crops in 1977 was about 377 million acres. Thus meeting 10 percent of U.S. energy needs from biomass farms means increasing acres used for crops by perhaps 100 percent. Additional land would also be needed for roads, farmsteads, storage facilities, and provisions for crop rotation.

These estimates are based upon current levels of energy use and agricultural productivity. Several factors could affect future acreage requirements for meeting 10 percent of U.S. energy needs. The first factor is that the past rate of growth in U.S. energy consumption may be curtailed. Second, the future growth rate of per acre agricultural output may continue to accelerate. These two factors could combine to produce a static, or even a more favorable, relationship in the amount of land needed for biomass production to supply a given share of U.S. energy consumption. Slowing increases in U.S. energy use will be difficult. But, maintaining or accelerating increases in the productivity of land will also be a formidable job. Past increases in agricultural land productivity were due in large part to increased use of energy intensive inputs--machinery, fuels, fertilizers, and pesticides. Future use of these energy intensive inputs will probably increase because the costs of substitutes--land and labor--are increasing at an even faster rate (11). Further increases of the energy inputs may result in lower energy output versus input ratios and increased environmental and health hazards posed by the inputs. The third factor to affect acreage requirements is the energy conversion rate. If efficiency of the processes converting the energy in biomass to another form of energy was increased, less acreage would be needed to maintain the same output. A fourth factor to affect acreage requirements is improvements in plant breeding.

Land Availability

The availability of land for biomass growth for energy will be limited by the land's use for food, feed, and fiber production and urban, recreation, and extractive uses. The total amount of land in different use categories has changed little since 1930 (table 7). Total cropland acreage peaked in 1930, then declined by 8 percent by 1974. Yet even with the advances in per acre productivity since 1950, acreage of cropland used for crops (not including idle cropland) is again on the upswing (table 8). Grassland pasture and range experienced the greatest changes, declining 40 million acres between 1930 and 1974. Grasslands have been converted to irrigated and nonirrigated cropland, replacing marginal cropland and cropland converted to special uses including urban and transportation areas. Other pasture as well as marginal cropland has grown up in trees, replacing woodland and forests, which have been cleared for cropland, pasture, and urban areas, or which have been formally converted to parks and other recreational reserves.

Table 7--U.S. trends in land utilization

Year	Cropland and idle land 1/	Grassland pasture and range 2/	Woodland and forest 3/	Other land 4/	Total land area 5/
	Million acres				
1930	413	719	601	171	1,904
1940	399	718	608	179	1,904
1950	409	700	601	194	1,904
1954	399	699	606	200	1,904
1959	391	696	609	206	1,902
1964	387	693	606	214	1,900
1969	384	692	602	219	1,897
1974	382	678	598	239	1,897

1/ Estimates of cropland harvested, crop failure, and cropland idle or fallow based on Census data. From 1954 on, includes adjustment for Census under enumeration; for 1959 and 1964, includes adjustment for farms with "whole farm" contracts under diversion programs but not meeting Census definition of a farm.

2/ Cropland uses only for pasture, permanent grassland pasture, and nonforested rangeland.

3/ Exclusive of reserved forest land in parks, game refuges, military reservations, and others. Includes commercial and noncommercial forest land, including woodland grazed.

4/ Includes special land-use areas, such as urban areas, defense facilities, highways and roads, farmsteads, parks, game refuges, and miscellaneous areas such as marshes, bare rocks, and deserts.

5/ Changes in total land area are attributable to changes in methods used in occasional remeasurements by the Bureau of the Census and to increases in the area of artificial reservoirs.

Sources: (10 and 30).

Land for special uses--urban uses, transportation, institutions, game refuges, parks, and barren areas--has increased by 66 million acres since 1930. Currently approximately a million acres of rural land are converted to urban and transportation uses each year, about a third of which comes from cropland (9 and 38).

The total amount of U.S. land devoted to each major rural use has remained relatively constant for 50 years. However, many acres of land have changed use as suitability is reevaluated in light of changing economic and social conditions and of technological innovations. Counterbalancing conversions of land to and from cropland, to and from pasture, and to and from forest resulted in little change in net inventories. For example, a case study of land use change between 1960 and 1970 in 53 counties experiencing severe

Table 8—U.S. cropland used for crops and cropland productivity, selected years, 1930-77

Year	Cropland used for crops 1/		Crop productivity per acre
	Million acres	1967 = 100	
1930	382	113	53
1935	377	111	54
1940	368	108	62
1945	372	109	67
1950	377	111	69
1955	378	111	74
1960	355	104	89
1965	336	99	100
1966	332	98	97
1967	340	100	100
1968	335	98	105
1969	333	98	106
1970	332	98	104
1971	340	100	112
1972	334	98	115
1973	353	104	115
1974	360	106	103
1975	368	108	112
1976	370	109	112
1977 2/	376	110	114

1/ Includes cropland harvested, crop failure, and cultivated summer fallow.
2/ Preliminary.

Source: Table 13 in (29). [The 1975, 1976, and 1977 unpublished data were provided by Donald Durost, ESCS].

pressure on the land base from population growth, found that cropland declined by 540,000 acres (fig. 1). Loss of cropland was 110,000 acres to pasture, 360,000 acres to idle land, 50,000 acres to forest, 270,000 acres to urban uses, and 20,000 acres to water, a total loss of 810,000 acres (38). During the same period in these rapidly urbanizing areas, 270,000 acres were converted to cropland, including 110,000 acres of pasture (cancelling loss to pasture), 130,000 acres from idle land, and 30,000 acres from forest and miscellaneous uses.

While the counterbalancing conversions of rural acreage among various uses have resulted in only small national net acreage changes, the dynamics of land change have had other impacts. Cropland has increased in quality as marginal cropland was retired and land more easily managed with newly developing technology was converted to cropland. The impacts

Major Land Use Shifts, 1961-70, 53 Urbanizing Counties
(Thousands of Acres)

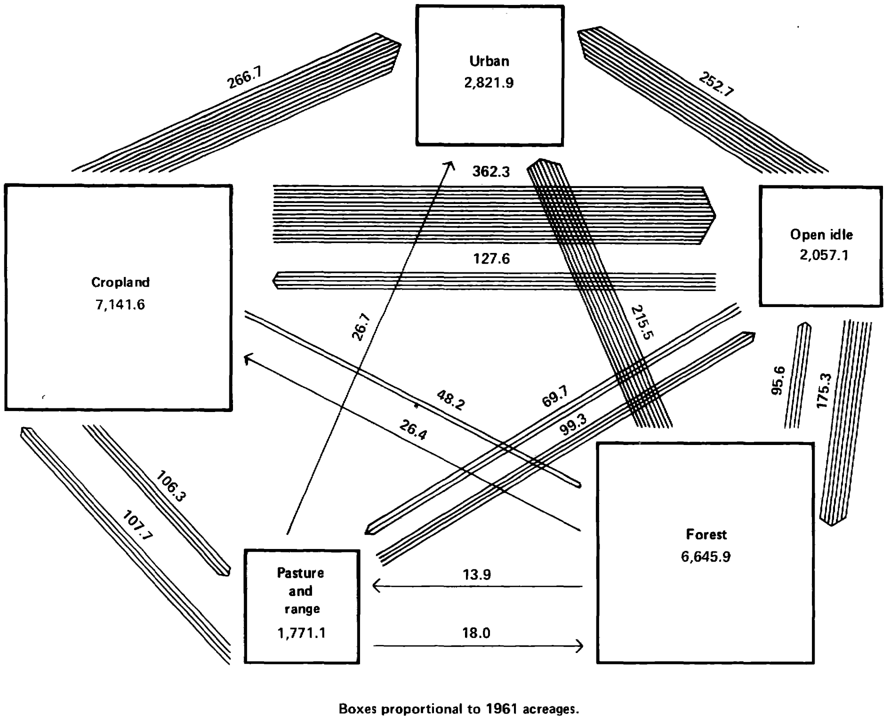

Figure 1

of declines in forest land on wood production are more far reaching than absolute acreage data indicate. Most of the clearing of forest land has occurred in the South, especially in the Delta area, and has involved converting highly productive bottomland forest to agricultural uses (table 9).3/ Decline in commercial timberland in the Mountain States frequently involved only a reevaluation of a site for commercial timber operations. Lands reverting to forest from the other uses tend to be poorer sites not only for crop and pasture production but also for forest production.

Acreage data on major uses of land show that more than a billion acres were in pasture, range, and forest land, which in biomass literature is frequently counted as the source of land for biomass crops. The availability of this

3/ States within each farm production region are: Northeast--Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland; Appalachia--Virginia, West Virginia, North Carolina, Kentucky, Tennessee; Southeast--South Carolina, Georgia, Florida, Alabama; Delta--Mississippi, Arkansas, Louisiana; Corn Belt--Ohio, Indiana, Illinois, Iowa, Missouri; Lake--Michigan, Wisconsin, Minnesota; Northern Plains--North Dakota, South Dakota, Nebraska, Kansas; Southern Plains--Oklahoma, Texas; Mountain--Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada; and Pacific--Washington, Oregon, California.

Table 9--Major uses of land, by farm production region, 1974

Land Use	48 States	Northeast	Appalachia	Southeast	Delta	Corn Belt	Lake States	Northern Plains	Southern Plains	Mountain	Pacific
	Million acres										
Cropland 1/	466.2	17.3	31.4	21.5	25.1	100.9	44.3	105.0	54.4	42.2	24.1
Grassland, pasture, and range 2/	595.2	2.9	7.4	10.5	7.6	14.5	6.1	73.9	112.1	305.5	54.6
Forest land 3/	598.5	69.7	73.1	76.3	50.5	29.1	52.3	4.5	33.3	119.9	89.7
Special uses 4/	150.3	15.8	9.3	12.3	4.7	12.7	10.6	7.4	9.1	43.9	24.4
Other land 5/	86.8	6.4	2.7	3.0	4.3	7.7	8.7	3.4	2.9	36.4	11.3
Approximate land area 6/	1,897.0	112.1	123.9	123.6	92.3	165.0	122.0	194.2	211.8	547.9	204.2

1/ Total acreage in crop rotation, including cropland harvested, cropland failure, cultivated summer fallow, soil improvement, idle, and cropland in rotation pasture.

2/ Grassland and other nonforested pasture and range in farms, excluding cropland used for pasture, plus estimates of open or nonforested grazing land not in farms.

3/ Excludes reserved forest land and some unreserved areas totaling about 31 million acres duplicated in parks and other special land uses.

4/ Urban, transportation, recreational, and other special land uses specified.

5/ Miscellaneous areas such as marshes, open swamps, bare rock areas, deserts, and special uses not inventoried.

6/ Approximate land area as established by the Bureau of the Census in conjunction with the 1970 Census of Population. Includes all dryland and land temporarily or partially covered with water, such as marshland, swamps, and river flood plains; streams, sloughs, and estuaries; canals less than 1/8 mile wide; and lakes, reservoirs, and ponds less than 40 acres in area.

Source: (14).

land for biomass production is limited not only by its demand for other uses and the availability of alternate sources for its current products, but also by other factors, such as quality of the land and the location of quality land with regard to water resources.

Land quality is an important variable in production costs and energy output/input ratios because per acre yields are sensitive to land quality. Production costs per unit of energy in biomass increase and energy output/input ratios decline as the quality of land in biomass production decreases.

The quality of land for biomass production also has important environmental impacts. Any expansion of cropped acreage will expose more land to soil erosion and make it a greater source of nonpoint water pollution. As the quality of land brought into production decreases, the dangers from pollution and soil degradation increase. Erosion of soil at rates higher than those for soil formation will contribute to higher production costs and lower energy output/input ratios because of decreased yields or increased inputs to check yield losses. Conservation measures to limit damage from pollution and erosion will increase the cost of the products from the land. Vegetative matter which is left on the land returns nutrients, maintains the organic content of soil and thereby improves soil structure, protects the soil from erosion, and lessens transport of nutrients, pesticides, and organic matter by runoff. The more biomass removed, the greater the loss of nutrients and organic matter and the greater erosion and polluted runoff. Such losses will be severe even on high quality land.

The only nationally comparable source of data on land quality was generated by SCS. In 1975, SCS conducted its Potential Cropland Study (5). 4/ SCS differentiated eight land capability classes depending on the land's suitability primarily for agricultural activities (table 10). Classes I through IV include land suited for cultivation and other uses, although limitations for continuous cropping are severe for class IV land. Classes V through VII include land generally not suited for cultivation, although with intensive management some of the land could be used for crops. Land in classes V through VII is best managed for pasture, forest, or wildlife habitat. The repeated and frequent cutting of vegetation, necessary for respectable yields of biomass, would strain these marginal lands. Class VIII lands cannot be managed for production of crops, pasture, or wood materials. In 1958 and 1967, in cooperation with the States, SCS had gathered land quality and land use information comparable to the 1975 data and published the data in State conservation needs inventories (28).

The rural land uses as defined by SCS differ somewhat from the Major Uses of Land series which summarize data from the Census of Agriculture, USDA's Statistical Reporting Service (now part of the Economics, Statistics, and Cooperatives Service) and the Forest Service, and other Federal agencies

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4/ Forty thousand points were located on rural, non-Federal land in the United States, and the capability of the land at each point for continuous cultivation was assessed. Land use potential for cropland development and problems associated with cropland development were also identified at each point. Information on the points was expanded for the 10 farm production regions.

Table 10--Characteristics of Soil Conservation Service's land capability classification

Class	Characteristics
Land suited for cultivation	
I.	Suited to a wide range of crops; nearly level; low erosion hazard; productive soils; can be intensively cropped; favorable climate.
II.	Some limitation on suitable crops; require conservation practices to prevent deterioration or improve air and water relationship within soil.
III.	Limitations restrict: (a) amount of clean cultivation; (b) timing of planting, tillage, and harvesting, and (c) choice of crops; require conservation practices more difficult to apply and maintain than those on class II land.
IV.	May be suited to only two or three common crops; yields may be low in relation to inputs over a long period; management and conservation measures more difficult to apply than for those on class III land.
Land generally not suited for cultivation:	
V.	Nearly level; limitations which are impractical to remove may include wetness, frequent overflow, stoniness, climatic limitation.
VI.	Continuing limitations which cannot be corrected may include steep slope, stoniness, severe climate; unusually intensive management necessary if used for common crops.
VII.	Unsuited for cultivation; impractical to supply pasture improvements or water controls.
VIII.	Cannot be expected to return significant benefits from management for crops, grasses, or trees.

Source: (28).

(see footnotes to table 9). SCS did not include Federal land in its inventories. SCS also delineated a category called "other land" which is non-Federal rural land not classified as cropland, pasture, rangeland, or forest. Other land includes farmsteads, feedlots, strip mines, gravel pits, rural nonfarm residences, investment tracts, coastal dunes, and other miscellaneous uses.

The SCS study shows that the quality of land varies by use (table 11). Crops are concentrated on high quality land. Specifically, 96 percent of U.S. cropland is classes I-IV land; 86 percent is classes I-III land alone. This concentration has become more pronounced since 1967 as poorer land has been converted to other uses and high quality land has been developed for cropland (table 12). Crop production is located on high quality land despite regional variability in the proportion of high quality land (table 11). The lack of regional variability in quality of land used for crops despite the regional variability in quality of all rural land emphasizes the interdependence of crop production and high quality land, a relationship which is also valid for production of a biomass crop. The vast majority of biomass production must occur on classes I-IV land.

The results from a study in Minnesota demonstrate one reason why biomass production should occur on high quality land (13). Using the universal soil loss equation, researchers estimated erosion losses for four Minnesota counties if all vegetative matter were removed from cropland. In all the counties, over 96 percent of cropland was classes I-III. Results for one county showed that with conventional tillage all vegetation could be removed from only 3 percent of the cropland without exceeding permissible soil losses. Under the same conditions, estimates for the other three counties were 22 percent, 43 percent, and 54 percent, respectively. With conservation tillage and with 1.5 to 2 tons of crop residues per acre left on the land, the percentages of corn acreage which could be cleared for each of the counties were 27 percent, 39 percent, 59 percent, and 89 percent, respectively. The vegetative matter which must be left in the field would decrease the biomass yield and thus increase the cost per ton of harvested biomass and per Btu of energy.

Acreages most likely to be physically suitable for biomass production are classes I-IV lands. Land for biomass production must come from the inventory of cropland, pastureland, rangeland, and/or forest land. The uses of land in the other category, such as farmsteads, roads, rural residences, and quarries, limit its potential for conversion to biomass or other crop production.

Biomass Production on Cropland

There were 384 million acres of classes I-IV cropland in the 48 contiguous States in 1975 (table 13). Idle cropland was under 20 million acres in 1977. Of these, only 5 million acres were idled purposefully, for example, in Government set-aside programs. Most idle cropland is not planted because of adverse local weather conditions or an illness, litigation, or probate involving the owner or operator during that particular year. Such a residual occurs each year and cannot be depended upon for food or biomass production.

Table 11--Proportion of rural land uses in capability classes I-IV by farm production regions, 1975 1/

Region	Cropland	Pasture and range	Forest	Other	All rural land
	Percent				
Northeast	92	75	31	67	49
Appalachia	94	66	38	74	55
Southeast	96	82	55	66	67
Delta	96	87	53	38	68
Corn Belt	98	75	45	81	84
Great Lakes	97	71	65	66	79
Northern Plains	95	41	47	78	69
Southern Plains	96	47	45	61	57
Mountain	94	17	6	10	27
Pacific	95	32	17	28	40
48-State average	96	39	42	53	57

1/ Data rounded to nearest percentage point.

Source: (5).

Table 12--Proportion of U.S. cropland by capability classes, 1967 and 1975

Class	1967	1975
	Percent	
I	8.3	8.3
II	42.8	47.0
III	32.3	30.7
IV	11.4	10.0
I-IV	94.8	96.0

Sources: (5, 28).

Table 13--Cropland by capability class and farm production region, 1975

Region	I	II	III	IV	I-IV 1/
			Million acres		
Northeast	1.0	7.7	5.4	2.0	16.0
Appalachia	2.3	10.1	5.1	1.5	19.0
Southeast	1.1	8.2	3.9	2.7	15.9
Delta	1.9	6.9	10.0	0.6	19.4
Corn Belt	10.5	48.1	21.8	4.8	85.1
Great Lakes	2.1	27.0	9.9	3.7	42.7
Northern Plains	9.0	45.2	23.4	9.0	86.6
Southern Plains	1.0	20.6	14.6	3.4	39.6
Mountain	1.8	9.2	19.5	7.8	38.3
Pacific	2.6	4.8	9.3	4.3	20.9
48 States 1/	33.3	187.7	122.7	39.8	383.5

1/ May not total due to rounding.

Source: (5).

The United States may again be entering a surplus agricultural production situation, ending the recent trend of full utilization of the cropland base. During the height of the surplus situation in the late sixties and early seventies, Government programs increased idle land to 60 million acres to hold down production. If surplus agricultural production again becomes a persistent problem, perhaps millions of additional acres might be idled again for long periods of time. Anticipation of using such land for biomass production is discouraged for several reasons. National and international production reverses, such as those experienced during the mid-seventies could again necessitate rapid expansion of cropped land. Climatic variability such as that which caused the production reverses in the early seventies should be anticipated. Many of the proposed biomass crops are perennials which would help mitigate the dangers from soil erosion and nonpoint pollution. Another advantage of perennial crops is that they do not involve costs for annual plantings. Establishment costs for alfalfa may be prorated over 3 to 5 years; planting costs for sycamores may be spread over 40 years. When temporarily excess cropland utilized for perennial biomass crops has to be quickly reverted to food or feed crops, cost of producing both the food and feed crops and biomass crops would be raised. There would be expenses first to remove the biomass crop and later to reestablish the biomass crop. Furthermore, the uncertainty of the availability of this land for biomass production means that the supply of the biomass crop is also uncertain. Cost for biomass processing facilities would be increased by this variability. The facilities would need to be equipped to process alternative raw material sources of energy or would stand idle.

The longer term trends of increasing foreign and domestic demand for agricultural products and of the slowing rate of increases in land productivity further restrict dependence upon such temporarily excess cropland for biomass production. Conversion of cropland to urban, mining, and related uses will put additional pressure on the cropland base.

Another way by which land presently cropped might be freed for raising biomass for energy is by substitution of vegetable protein for animal, especially red-meat, protein in the American diet. For instance, about 60 percent of feed grains by weight consumed by all livestock is used for beef cattle, hogs, and sheep (2). 5/ Land in feed grains accounted for 107 million acres in 1976 (32). Assuming per capita consumption of red-meats declined enough so that it could be met primarily from "grass fed" animals and from imported meats, perhaps up to 60 million acres of high quality land could be made available for biomass production. A number of factors weigh against realization of this shift. Americans would not only have to dramatically decrease consumption of their preferred meats, but also settle for poorer quality meat (given present perception of quality). Pressure for greater, not less, feed grain production is likely not only because of increased U.S. and world population, but also because rising income levels in foreign countries have resulted in a growing per capita demand for animal protein and, consequently, feed grains to be fed to the livestock.

Biomass Production on Pasture, Range, and Forest Land

The current cost of and returns to crop, pasture, and forest production are such that biomass production is likely to compete more successfully for land inputs with pasture and forest uses than with crop use. Conversion of pasture, range, and forest land entails finding alternate sources for the feed and fiber production from this land. The pasture and forest land which will have the greatest potential for biomass crops is also the land which is most productive for pasture or forest uses. Of the 221 million acres of classes I-IV pasture and rangeland, 72 percent is land in classes III and IV which has limitations both restricting choice of crops and the amount of clean cultivation and also requiring conservation practices (table 14). Of the 168 million acres of classes I-IV forest land, 75 percent is in classes III and IV (table 15). A total of 380 million acres of pasture, range, and forest land have fair suitability for crop production. Of these 380 million acres, 73 percent--or 275 million acres--need considerable conservation measures if the land is cultivated.

Converting present pasture, rangeland, and forest land to biomass production means that the current and increasing future demand for forage and fiber must be met while utilizing less and perhaps poorer quality land. About two-thirds of urban and related development occurs on pasture and forest land, further reducing acreages available for feed and fiber production. At the same time, demand for wood and fiber products may be enhanced not only by growing population and increasing per capita consumption but also by increasing competitiveness with synthetics derived from oil or coal. The productivity of current forest lands could be greatly improved, but this will require increased invest-

5/ The proportion of feed grains consumed is 32 percent for beef cattle, 28 percent for hogs, 12 percent for dairy cattle, and 17 percent for poultry.

Table 14--Pasture and rangeland, by capability class and farm production region, 1975

Region	I	II	III	IV	I-IV 1/
	Million acres				
Northeast	2/ -	1.8	2.2	1.4	5.5
Appalachia	0.9	5.1	5.0	3.5	14.5
Southeast	.3	3.4	5.6	6.3	15.5
Delta	.7	4.5	4.3	1.3	10.9
Corn Belt	1.3	6.9	8.4	5.4	22.0
Great Lakes	-	2.0	2.4	1.2	5.6
Northern Plains	.5	10.0	14.6	9.4	34.5
Southern Plains	2.3	17.7	27.0	18.7	65.7
Mountain	-	3.7	13.1	17.7	34.6
Pacific	.1	1.5	5.0	5.4	12.0
48 States 1/	6.1	56.7	87.8	70.3	220.8

1/ May not total due to rounding.
2/ Dash indicates value less than 0.06.

Source: (5).

ments in improvements and protection from fire, insects, and disease (20). Adaptation of processing advances could increase final production from forest lands. Perhaps a more difficult task in upgrading timberland will be educating and providing financial assistance to encourage the owners of small tracts of forest land, who control three-fifths of all commercial timberland, to make the necessary investments. Cropland and pastureland productivity has increased as farmers have increased their management expertise. Increased forest productivity depends upon better management. Studies of owners of forest land in the Northeast show that the majority of owners do not hold forest land for commercial production but for residential, recreation, or speculative use (17, 18, 19). Such owners need to be educated about the esthetic and financial rewards of forest management if the productivity of forest land is to be increased.

The availability of land for biomass production will be further limited by other factors. Adequate local precipitation will be a prerequisite for biomass production both to minimize the costs of production per unit of energy output and also to maximize the energy output/input ratio. Irrigation with water transferred from an outside basin would make energy generation

Table 15--Forest land by capability class and farm production region, 1975

Region	I	II	III	IV	I-IV 1/
			Million acres		
Northeast	0.3	5.2	9.0	5.2	19.7
Appalachia	.6	5.6	9.5	8.4	24.1
Southeast	.3	7.9	12.3	15.5	36.1
Delta	.2	6.1	11.3	6.2	23.8
Corn Belt	.6	3.4	3.5	3.9	11.4
Great Lakes	2/-	6.2	8.4	13.0	27.6
Northern Plains	.1	.5	.1	-	.7
Southern Plains	-	1.4	4.6	1.1	7.1
Mountain	-	-	.1	.8	.9
Pacific	-	1.1	1.8	3.3	6.2
48 States 1/	2.2	37.4	60.7	57.3	157.5

1/ May not total due to rounding.
2/ Dash indicates value less than 0.06.

Source: (5).

from biomass even less efficient and more costly. 6/

In much of the United States, water is available locally for production of biomass for energy. In the humid eastern portion of the country, rainfall is sufficient for biomass production, although supplemental irrigation might insure higher yields. Irrigation will be a necessity in the drier western areas of the country where the amount of precipitation is low and highly variable.

Lines of the same average annual precipitation tend to lie in a north to south direction, with some deflection to the east above 40° N latitude (fig. 2). Of USDA's 10 farm production regions, 6 are east (that is, to the wetter side) of the 28-inch isopleth. Precipitation within these regions is dependable. Land in two other regions, the Northern and Southern Plains, falls between the 16-inch and 28-inch precipitation lines. The Mountain and Pacific regions are west of the 16-inch precipitation lines. Perhaps an even more severe moisture constraint in the four drier production regions is the spatial and year-to-year variability of precipitation. The spatial and temporal reliability of rainfall is proportional to the average yearly

6/ Alich hypothesized a decline in the energy O/I ratio, from 60/1 to 7/1 for biomass production involving interbasin water transfer (1). Alcohol produced from such biomass would mean a negative energy O/I ratio for fuel production (16).

Average Annual U.S. Precipitation

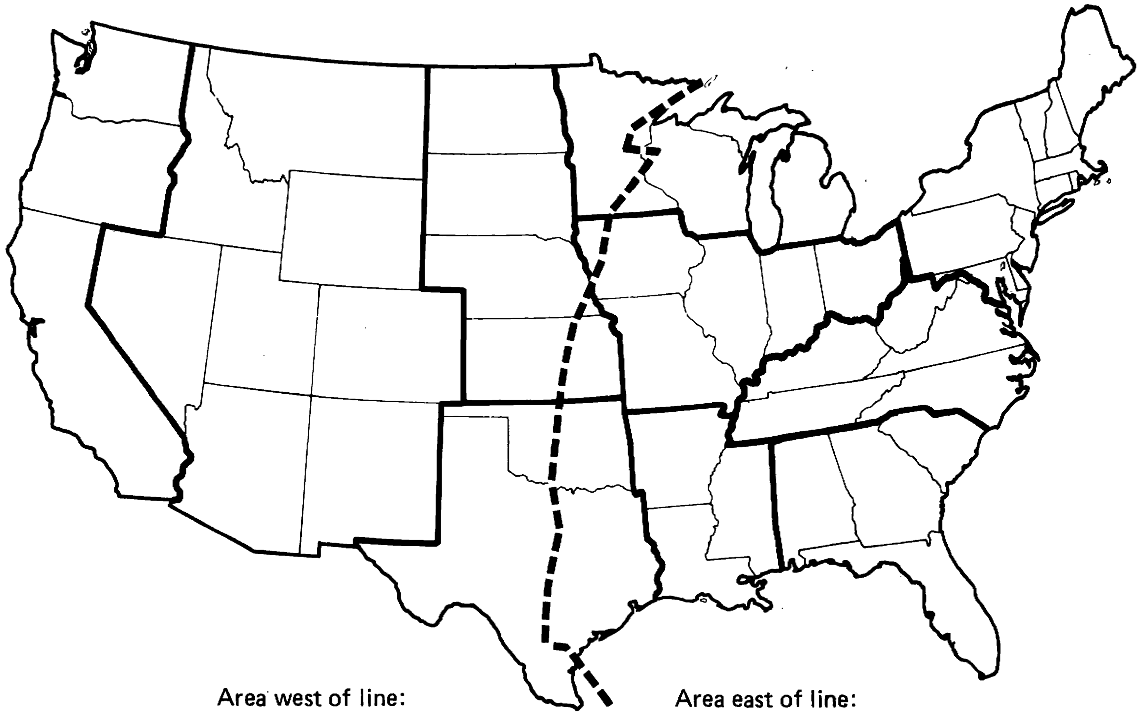

Figure 2

amount of precipitation. For these reasons, land suitable for biomass for energy cultivation would more likely be in the six eastern farm production regions which receive at least 28 inches of average annual precipitation. This would be true especially in the lower latitudes, which have higher rates of potential evapotranspiration. Because of the higher amount, the homogeneous pattern, and year-to-year dependability of rainfall in the six eastern farm production regions, biomass yields would be higher and less variable in these areas, without the capital and energy intensive irrigation schemes needed to obtain similar yields in the West.

The moisture in the eastern regions is a mixed blessing in terms of biomass production. Although production is assured, drying and storage of biomass would be more difficult in this humid environment and would increase the final cost of energy from biomass.

The SCS potential cropland study indicates there are 216 million acres of classes I-IV pasture, range, and forest land in the six humid eastern farm production regions (fig. 3). Other factors besides water availability inhibit the conversion of this land to crop or biomass production. In the Potential Cropland Study, SCS further classified land as to its potential for conversion to cropland and identified problems which would limit probable development as cropland. The problems identified were the following: small tract, isolated tract, small ownership unit, held for

Classes I-IV Pasture, Range; and Forest Land

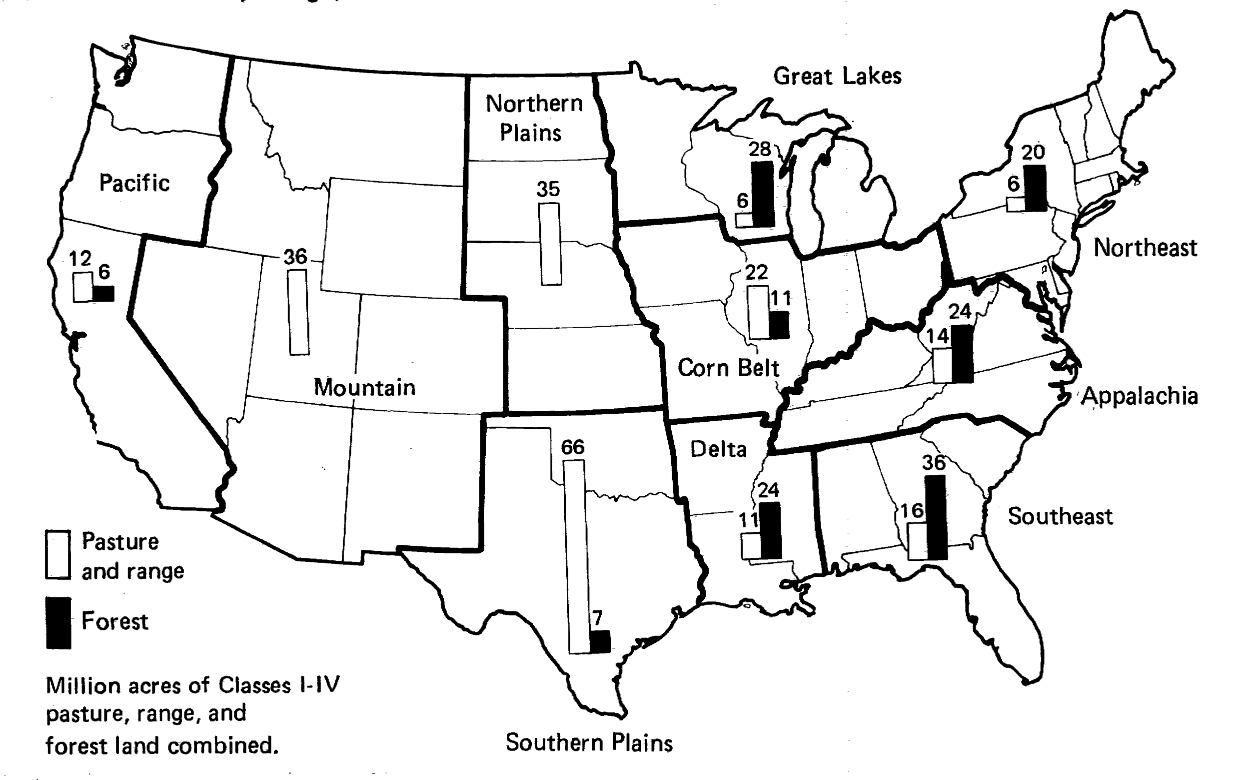

Figure 3

urban use, commitment to noncropland use, short growing season, lack of dependable water, high density forest, environmental impacts, erosion control, drainage outlet, seepage, seasonable high water table, wetland types 3-20, recurrent flooding, high erosion hazard, stone or rock outcrops, accumulation of salts, thick undesirable overburden, and very low fertility. SCS also estimated whether onfarm, multifarm, or project actions would be necessary to counteract these problems.

Land was classified as having high potential for cropland development if, based on the favorable 1974 price-cost relationships, the probability of conversion to cropland within the next 10-15 years was high. Classification as high potential was contingent on evidence that similar land had been converted to cropland in the last several years. Much of the high potential land had minor problems, but the problems were not severe enough to seriously limit development. Zero potential land was in deserts, mountains, or preempted by other uses. Low potential land had one or more serious problems or obstacles to development. Medium potential land was the residual.

Of the classes I-IV noncropland, 74 million acres--or 18 percent--were identified as having high potential for cropland development (table 16). Approximately 40 percent of this acreage had either no problems or such minor

Table 16—Development potential of classes I-IV noncropland, by region, 1975 1/

Region	Potential for cropland development			
	High	Medium	Low	Zero
	Millions acres			
Northeast	2.0	1.0	13.8	14.4
Appalachia	9.2	2.0	21.2	8.6
Southeast	10.0	7.7	27.1	10.2
Delta	7.4	3.2	19.3	6.5
Corn Belt	11.3	3.3	14.0	10.9
Great Lakes	4.2	.6	20.0	16.3
Northern Plains	11.2	3.9	13.8	9.7
Southern Plains	9.5	1.2	62.6	.7
Mountain	6.5	3.8	22.5	3.7
Pacific	2.6		13.1	5.7
48 States 2/	73.8 3/	26.8	227.5	86.5

1/ Includes 221 million acres of pasture and rangeland, 158 million acres of forest land, and 36 million acres of other land.
2/ May not total due to rounding.
3/ Less than 3 million acres were other land.

Source: (5).

problems that no development was necessary before the land could be used for crops. The remaining 60 percent would require onfarm, multifarm, or project development to counteract the problems identified. An additional 6 percent of the classes I-IV noncropland—or 27 million acres—had medium potential for cropland development. Over 80 percent of this acreage would require at least onfarm development. Thus, there are about 33 million acres of U.S. land that have high potential for cropland development and such minor problems that the land could be used for food, feed, and perhaps biomass crops without special development. About 17 million acres of this land was in the 6 more humid farm production regions. The remainder, about 40 million of the 74 million acres of high potential land, would require additional development if it was used for crops, and this would be reflected in costs of products.

Federal Lands

The estimates that are based upon SCS data of land potentially available for production of food, feed, fiber, or biomass crops do not include Federal lands. About 10 percent of Federal lands in the 48 contiguous States is located in the 31 eastern States. According to a study conducted at the request of the Public Land Law Review Commission, of the 371 million acres of land administered by the Federal Government in the 17 western coterminous States, 2.0 million acres are suitable for intensive dry land agriculture (26). Another 1.3 million acres are suitable for irrigated cultivation and have water available. The bulk of land potentially suitable for intensive cultivation, 35 million acres, needs irrigation water which is not available. Costs of irrigating these acres of land would likely exceed the costs of developing land by clearing and drainage in the humid East.

CONCLUSIONS

Growing concern about the depletion of the finite supplies of fossil energy resources has accelerated the search for alternate sources of energy. Capturing solar energy in vegetative biomass and using the biomass to produce heat, electricity, fuels, and petrochemicals is now being considered as one energy option. The biomass may be produced as an "energy crop" or it may be generated as residues of the production or consumption of other organic materials.

Under present technology, the cost of energy contained in biomass grown on energy farms is several times the current cost of energy contained in crude oil or coal. Increases in cost of fossil and nuclear energy will not make the energy from biomass competitive, because of the large energy inputs that are needed for biomass production, transportation, and processing. Thus, increasing energy costs would be passed through to costs of energy from biomass. The cost of energy from biomass could best be made more competitive by two developments. First, productivity could be greatly increased relative to all inputs including energy. Second, the efficiency of the conversion processes must be greatly improved.

The feasibility of growing biomass for energy is dependent in part upon the availability of land. The availability of land depends upon the land quantity and quality requirements for biomass production and the ability of biomass production to compete economically with other land uses. The relationship between biomass production and land inputs will be governed by the same biological, production, cost, and energy considerations which affect crop and forest production. The energy output/input ratio for biomass or other crop production improves if the crop is grown on high quality land. Adequate local water supplies also raise the potential energy output/input ratio for biomass or other crop production. The dangers from and, thus, the costs to minimize environmental degradation from nonpoint pollution and soil erosion are lower on high quality land. Overall, per unit costs of growing biomass or other crops are inversely related to land quality and proximity to water sources. Thus, biomass production and other food, feed, and fiber production are drawn to better quality land and locally available supplies of water.

Currently, to produce 1 percent of U.S. energy needs from biomass farming would require at least 10 million acres of good to very good quality land. If biomass crops are relegated to lower quality land, the estimate would be closer to 30 or 40 million acres. Higher productivity and greater efficiency of the conversion process would put the land requirement closer to the lower figure. Converting such quantities of good land to biomass production must occur at the expense of other land uses and would necessitate major readjustments in the U.S. supply of food, feed, and fiber products.

With careful managment much of the 470 million acres of cropland in the 48 coterminous States might be suitable for growing biomass. SCS land quality classes I-IV contain 96 percent of the cropland. The substantial increases in productivity of cropland during the last 40 years have at times outpaced increases in domestic and foreign demand and have resulted in land set-aside and grain reserve programs. However, there are problems involved in using the cropland idled in these programs for biomass production. During periods of adequate agricultural inventories, using acres set aside from food and feed production for biomass production and then relinquishing these set-aside acres to crop production during times of inventory depletion, would mean that biomass must be stockpiled or that substitutes for biomass must be available. The bulkiness of biomass and its perishability make biomass extremely costly to stockpile relative to its market value as a source of energy. Facilities capable of processing alternative feedstocks might be more expensive. Using set-aside crop acreage for biomass production would be even less viable if the biomass crop was a perennial. Costs would be incurred in clearing the land for the food crop and in reestablishing the biomass crop.

Biomass farming is more likely to be competitive for land with pasture, range, and forestry uses. Nearly 1.2 billion acres of land in the 48 coterminous States are in pasture, range, and forest use. This land is generally of poorer quality than cropland. Only about 40 percent of noncropland is in capability classes I-IV. Much pasture, range, and forest land is extensively utilized and is thus less critical to the Nation's food and fiber production. Diversion of extensively managed pasture, range, and forest to biomass production would less severely affect U.S. production than would the diversion of cropland or intensively managed pasture and forest land. However, the extensively managed forage and woodlands generally have severe quality limitations which would also limit these lands' usefulness for biomass production. Lower biomass yields mean increased per unit costs of energy production. Subjecting marginal land to the high input levels and the repeated radical clearings necessary for acceptable biomass yields would greatly increase the danger of environmental degradation from nonpoint sources of pollution and erosion. Conservation practices to counteract these harmful consequences would be costly.

The better quality pasture, range, and forest lands are the most productive. Conversion of these lands to biomass production means that alternative sources of, or substitutes for, the feed and fiber products of these lands must be found. Results of an SCS study of potential cropland showed that there were approximately 74 million acres of classes I-IV noncropland which had high potential for cropland development. An additional 27 million acres of classes I-IV noncropland had medium potential for development. However, most of this land had problems which would require private or public investment to remedy these problems. Thus, of the 100 million acres of classes I-IV noncropland with high and medium potential for development, only about 35 million acres required no investment to overcome institutional or physical problems. About half this acreage was in the 31 humid Eastern States. This land might have considerable potential for biomass production if alternate sources for the present feed and fiber crops of these pastures and woodlands were available at comparable costs.

Two factors could substantially affect the availability of land for biomass production—a change in demand for agricultural and wood products and/or a change in productivity. Demand for food, feeds, and fibers will increase. The question is how rapidly. Although the U.S. birth rate is declining to the replacement rate, absolute population continues to increase because of the age structure of the population and continuing immigration. World population continues to grow, as less developed nations have been unable to slow their population growth rates. Rising incomes have allowed increasing numbers of people worldwide to rely on diets rich in animal protein, increasing the demand upon cropable land for feed grain and forage production. U.S. agriculture will face growing economic and political pressure to meet the food demands generated by rising populations and incomes. Currently, 100 million acres are used to produce agricultural products exported by the United States (29). In 1950, only 50 million acres were used to produce agricultural exports.

The productivity of U.S. land has doubled since the thirties. Higher productivity resulted from technological advances, improved management, and a shift to higher quality land. Technological advances have provided crop varieties, fertilizers, and pesticides at advantageous prices. Such improvements have been rapidly utilized by better informed and more responsive farm operators. Favorable climatic conditions also aided the dramatic rise in productivity, as did the retirement of marginal cropland and pastureland concurrent with the development of better quality agricultural land. During the early seventies, per acre productivity had stabilized, causing concern about future increases in land productivity. Will the upturn in costs of inputs such as fuels, fertilizers, and pesticides and the effect of diminishing returns per levels of input result in either extending this plateau of productivity or in slowing the rate of increase in per acre productivity? What is the probability that poorer climatic conditions will exist? Further upgrading the cropland base by land conversion means decreasing the quality of remaining land for other uses.

Despite its upward trend, productivity has leveled off for short periods during the last 30 years. Initiation of productivity increases are likely to occur as values, reflected in product prices, readjust to allow for increased investments. Thus, if biomass can compete for land, independently or through subsidization, there will be pressure to utilize the land more intensely for crop production and, thus, will likely result in higher product prices. Factors most likely to reinstate the upward trend in productivity are further improvements in plant and animal breeding, increasing responsiveness to growth stimuli such as water and fertilizers, and increasing defenses against disease. Increases in the cost of synthetics may enhance the competitiveness of natural fiber products, such as lumber, paper, and cotton, which will permit greater investment in productivity enhancing management practices and technologies.

Perhaps the most important long-term factors slowing the rate of increase in land productivity for agricultural, forest, or biomass use, will be:

(1) increased costs of all inputs which are dependent upon energy for their manufacture or transport (this would include even water and conservation measures) and (2) sanctions against the use of certain chemicals and against land use practices which would be occasioned by increased concern over the environment resulting from greater knowledge of the dangers.

Slowing of productivity increases and growing demand not only for food and feed but also for natural fibers will make good land an even more highly valued input. Demand for land for living, working, recreation, and mining will intensify the competition for rural lands. Biomass production is likely to face even stiffer competition for land in the future.

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